

# Application of Digital Sampling Techniques to a “Single Chip Telescope” for Isotopic Particle Identification

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Introduction



Example of a custom digital sampling system



Performances of On-line Digital Signal Processing:

- Amplitude measurements (Energy)
- Timing measurements (Pulse Shape Analysis – ToF)



Pulse Shape in a **reverse mount** Silicon.



Application to a “new” detector: the Single Chip Telescope

- Description of the detector
- Results of the very first prototype



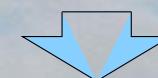
Conclusions.



One of the main purposes of nuclear dynamics studies with future RNB facilities is the investigation of nuclear matter far from the stability line



Strong requirements on experimental capability of **charge** and **mass** identification.



High detection granularity, and thus a very **high number** of electronic channels.

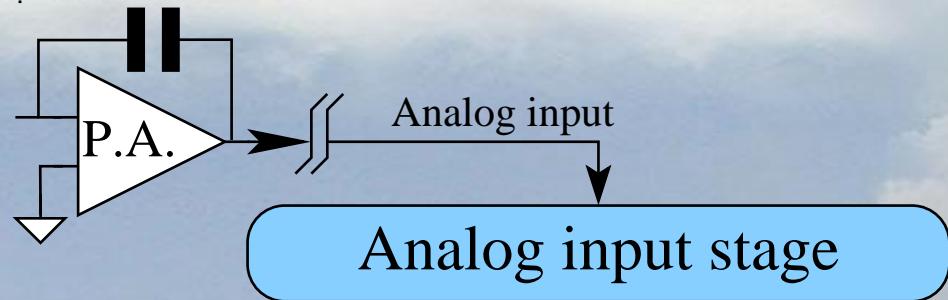
Both requirements can benefit from the use of **fast digital sampling techniques**:

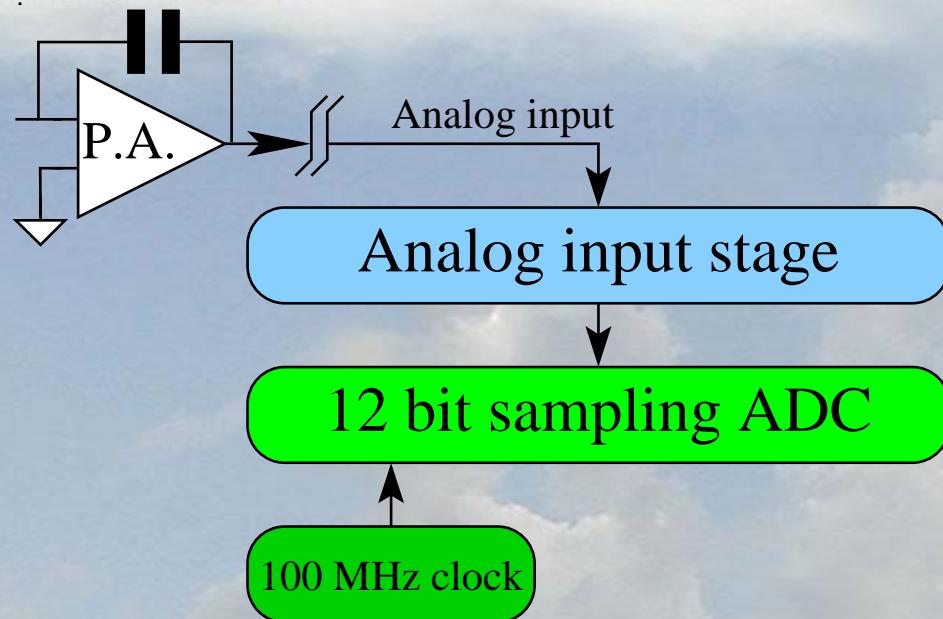
- Performances as good as standard analog techniques
- Much simpler electronic setup: a single fast Analog to Digital Converter can extract all the information needed from a detector preamplifier (energy, pulse shape, timing)  
⇒ much lower costs.

## A custom sampling system

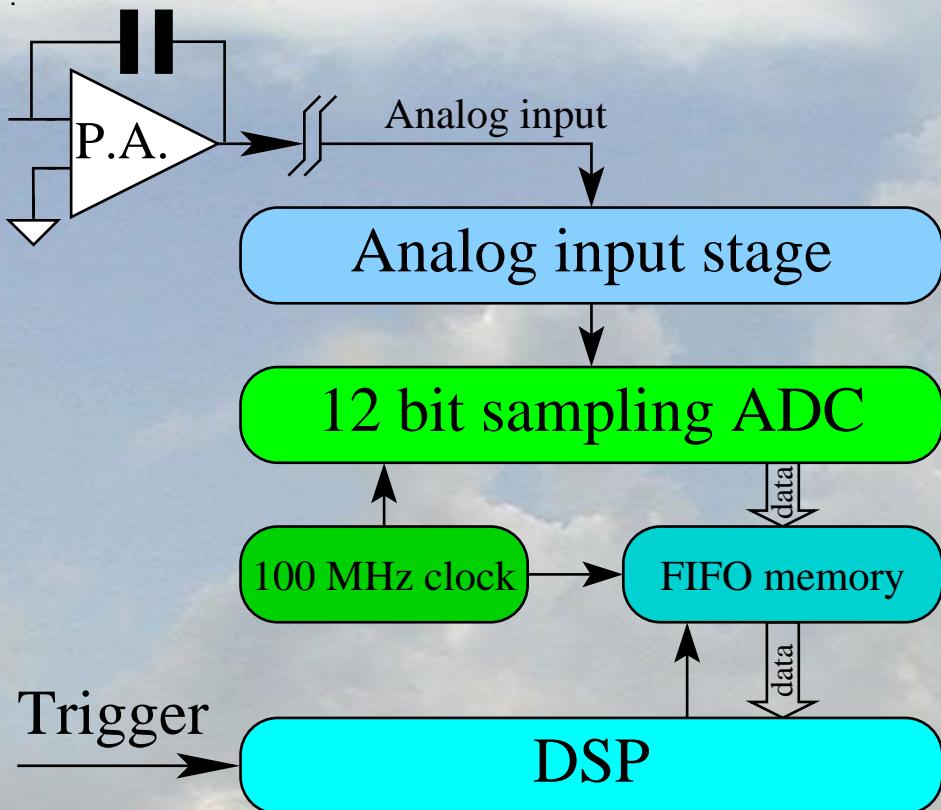


## A custom sampling system

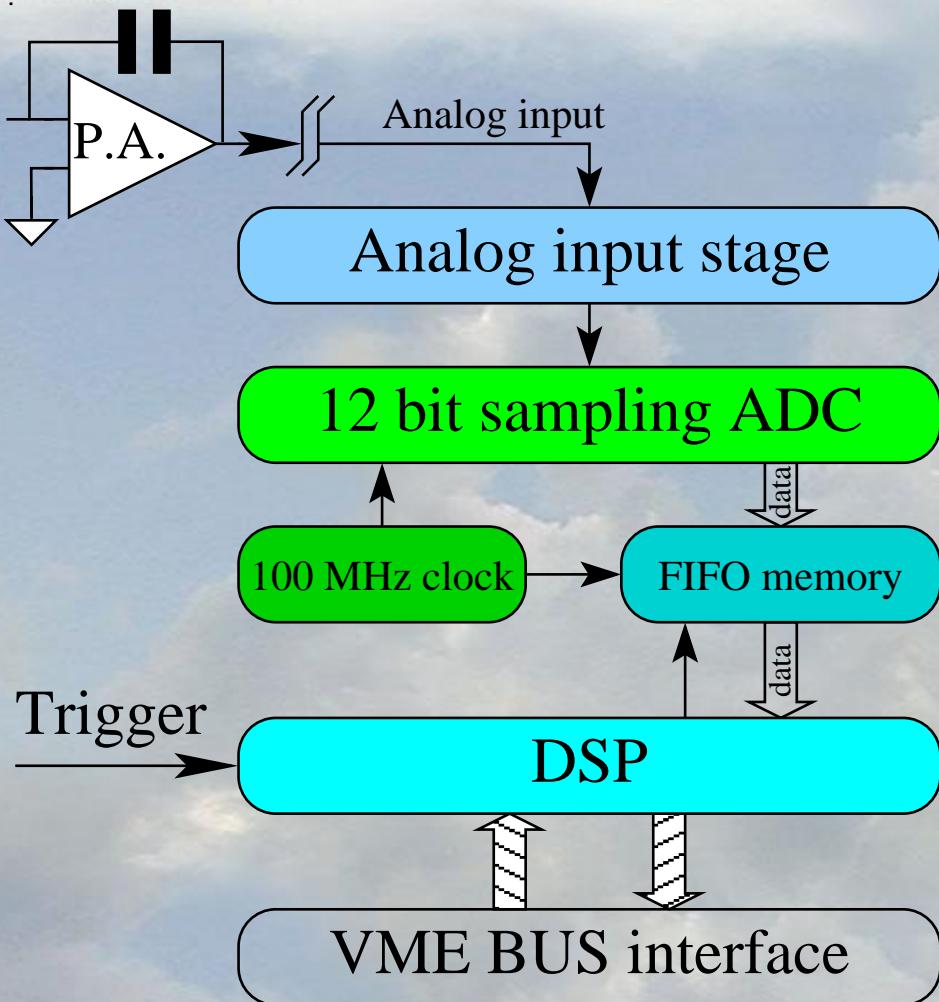




## A custom sampling system



## A custom sampling system



Custom system designed and built in Florence.

- Constant phase antialiasing input stage.
- **100 MSamples/s, 12 bit** fast Analog-to-Digital Converter.
- Digital Signal Processor (DSP) for **on-line** processing of detector signals: **one processor can compute many variables**
- Data readout via VME bus.

A first prototype (without DSP) is described in: L.Bardelli, M.Bini, G.Poggi, N.Taccetti,  
Nuclear Instruments and Methods in Physics Research **A491** (2002) 244-257



## High resolution (12 bit) fast AD converter

Electronic resolution that **well compares** with standard analog **high-resolution** and **high dynamic range** systems.

## Digital Filters

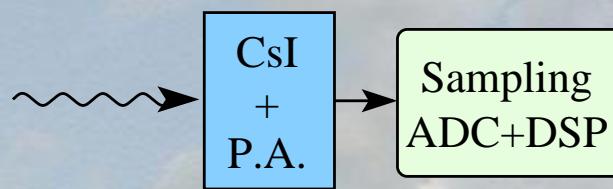
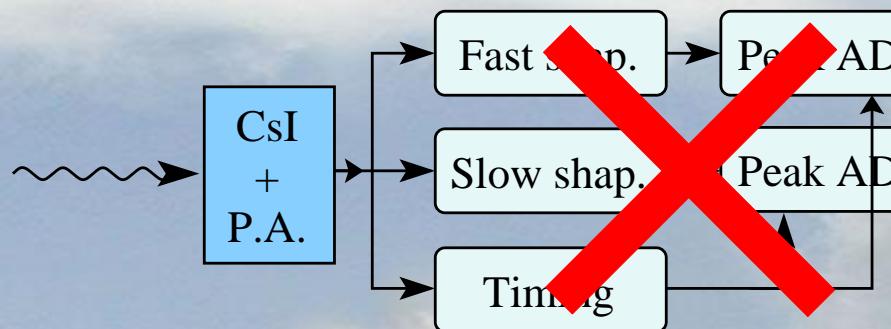


Digital versions of analog filters (i.e. spectroscopy amplifiers, . . .)

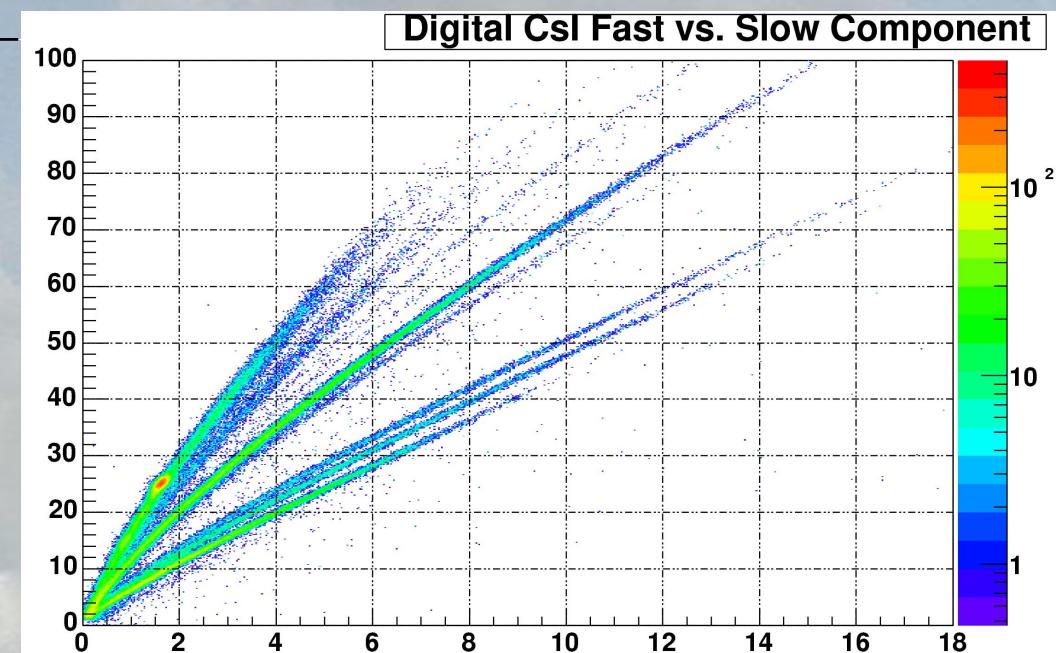
**New** (better) filters, for example *optimal filtering*

Some experimental examples II 

## Pulse Shape in CsI

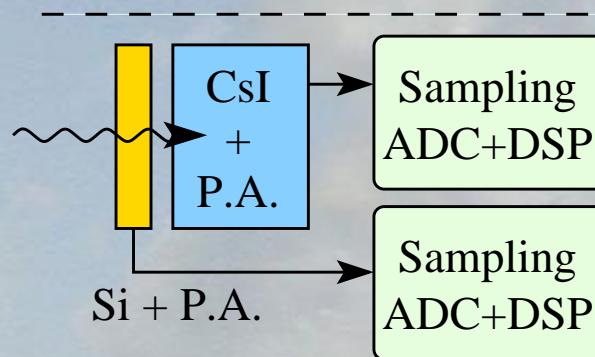
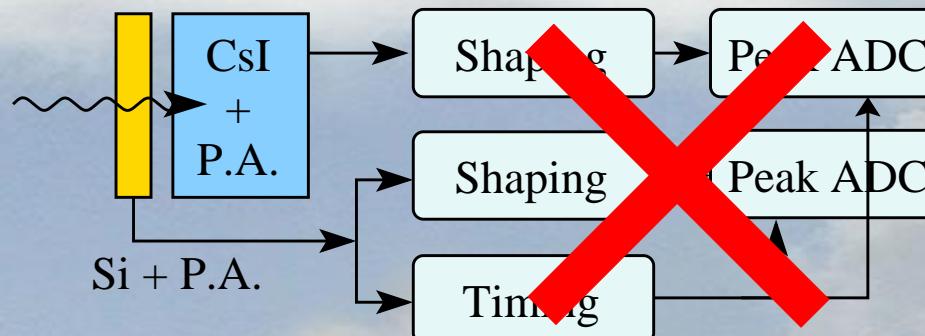


Much simpler  
digital electronic chain

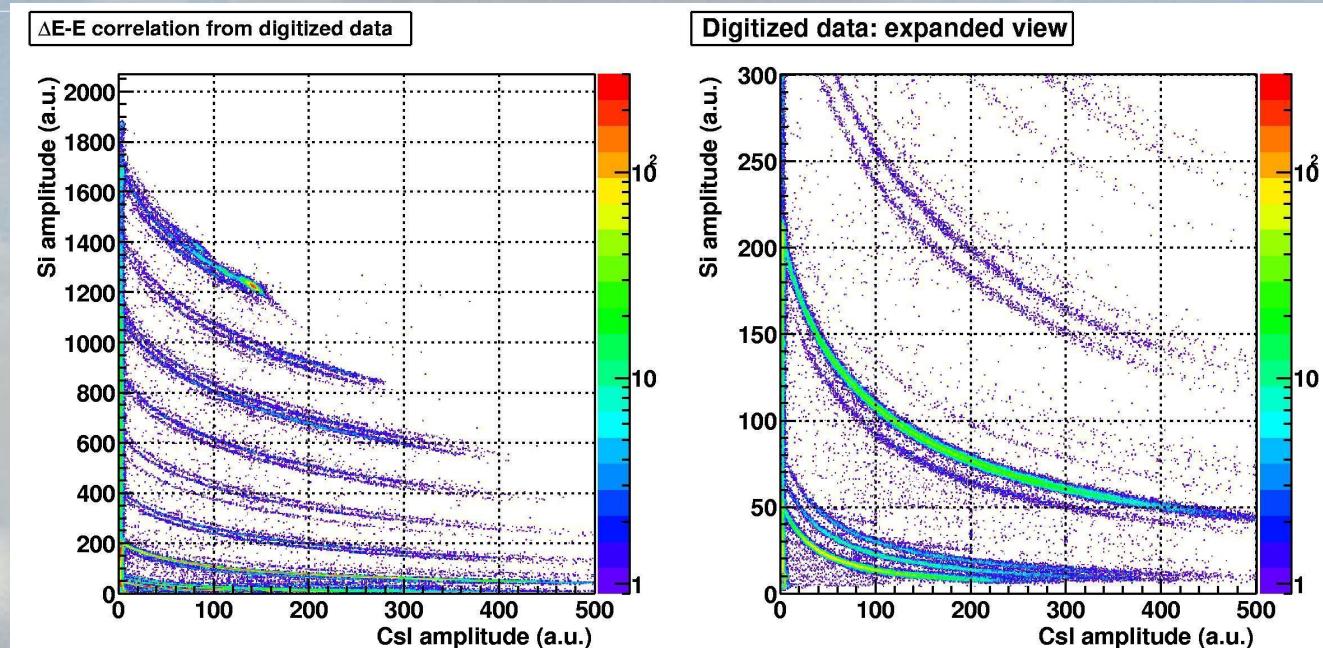


Standard Fast vs. Slow correlation for a CsI scintillator,  
obtained using a 12 bit fast sampling ADC and processing data with  
two **digital** semigaussian filters ( $\tau_{fast} \simeq 700$  ns,  $\tau_{slow} \simeq 2$   $\mu$ s).

## Si-CsI telescope: $\Delta E-E$



**Simpler digital  
electronic chain**



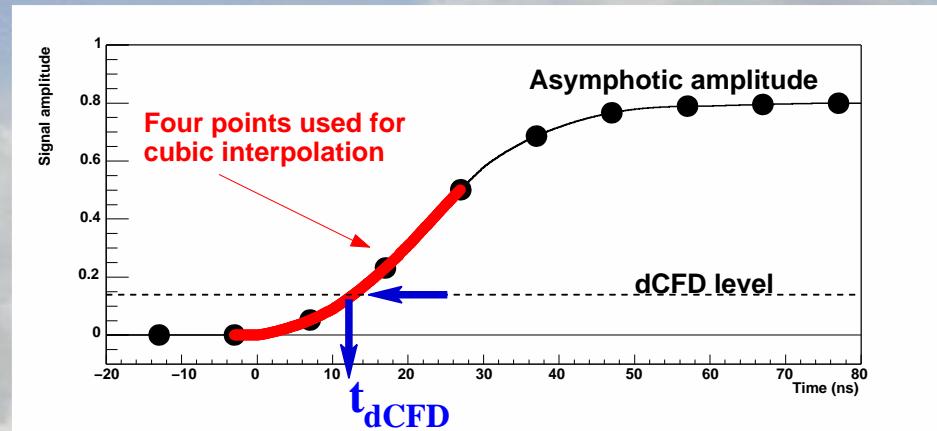
Standard  $\Delta E-E$  correlation using digital semigaussian filters:  
**Both high and low ranges with a single AD converter for  $\Delta E$**

## Timing measurements 1

Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**:

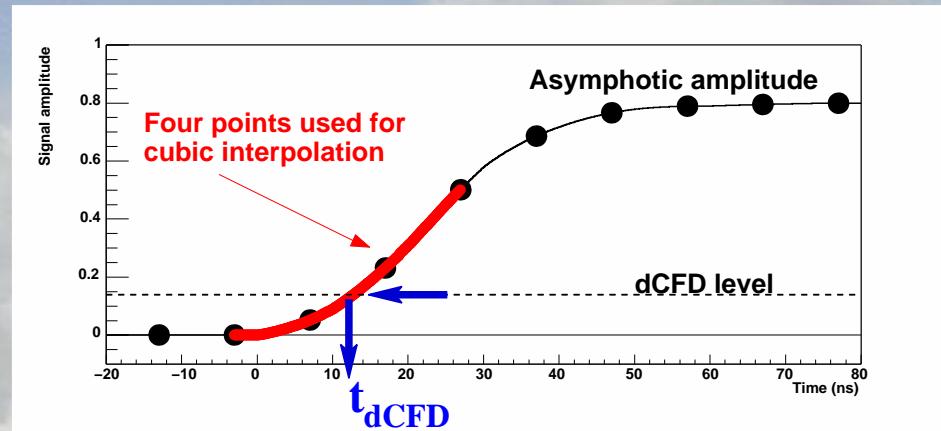


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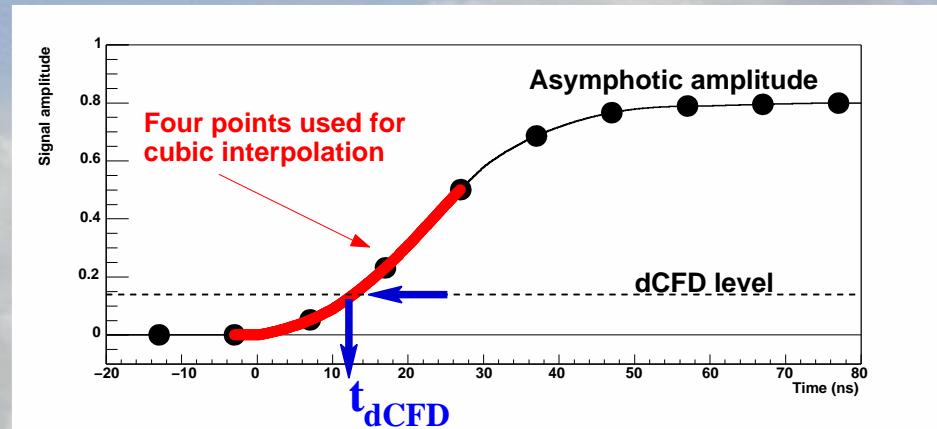
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- 1 Find the asymptotic amplitude  $A$  of the signal

## Timing measurements 1

Timing measurements for Pulse Shape Analysis can be achieved using a **digital Constant Fraction Discrimination**:



- 1** Find the asymptotic amplitude  $A$  of the signal
- 2** Interpolate the time where  $S(t_{\text{dCFD}}) = f \cdot A$  (**cubic interpolation needed**)

This is **different from what analog CFDs perform!**



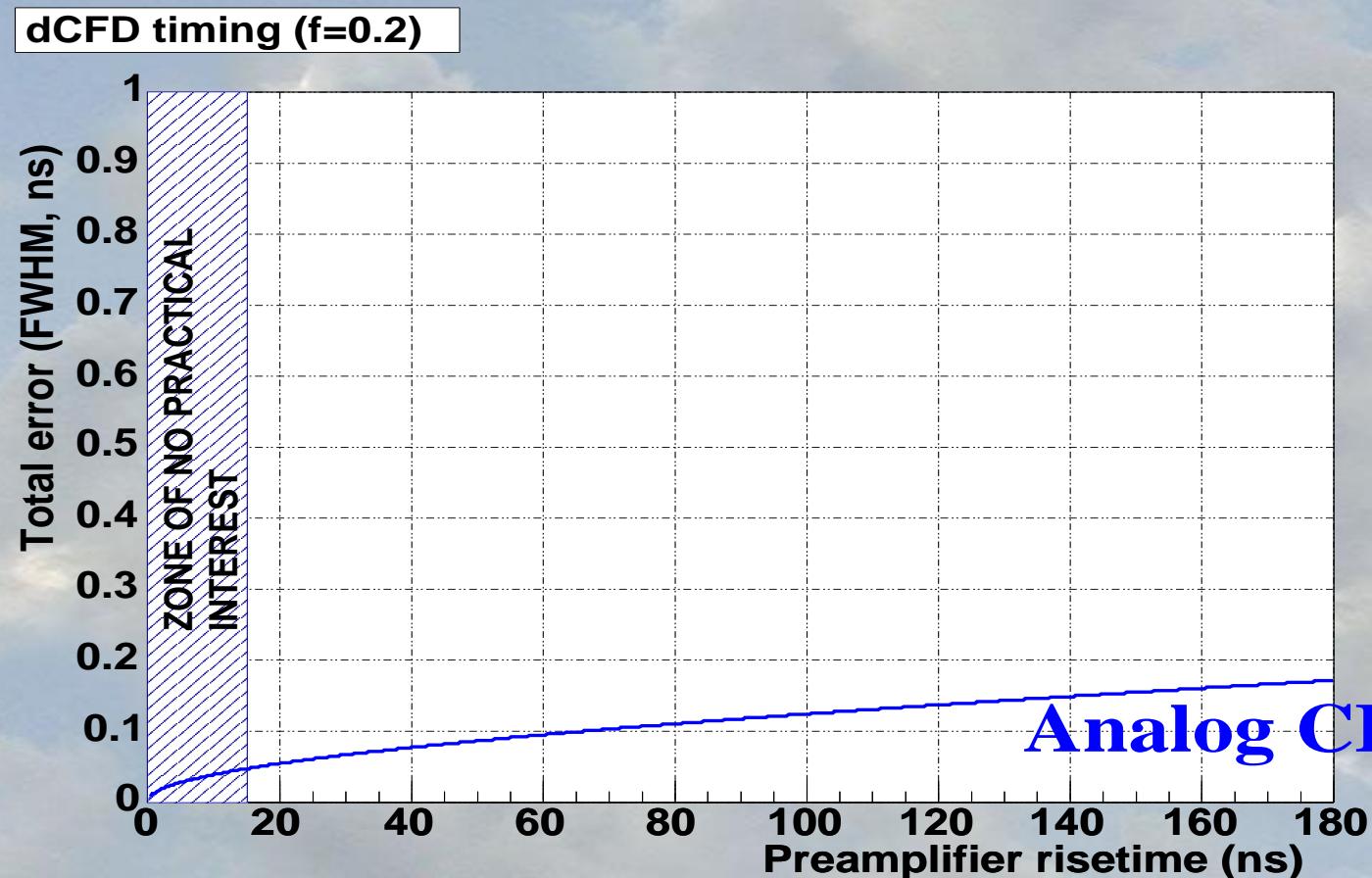
## Which AD converter ?

Realistic simulations: (L.Bardelli *et al.*, submitted to NIM A)



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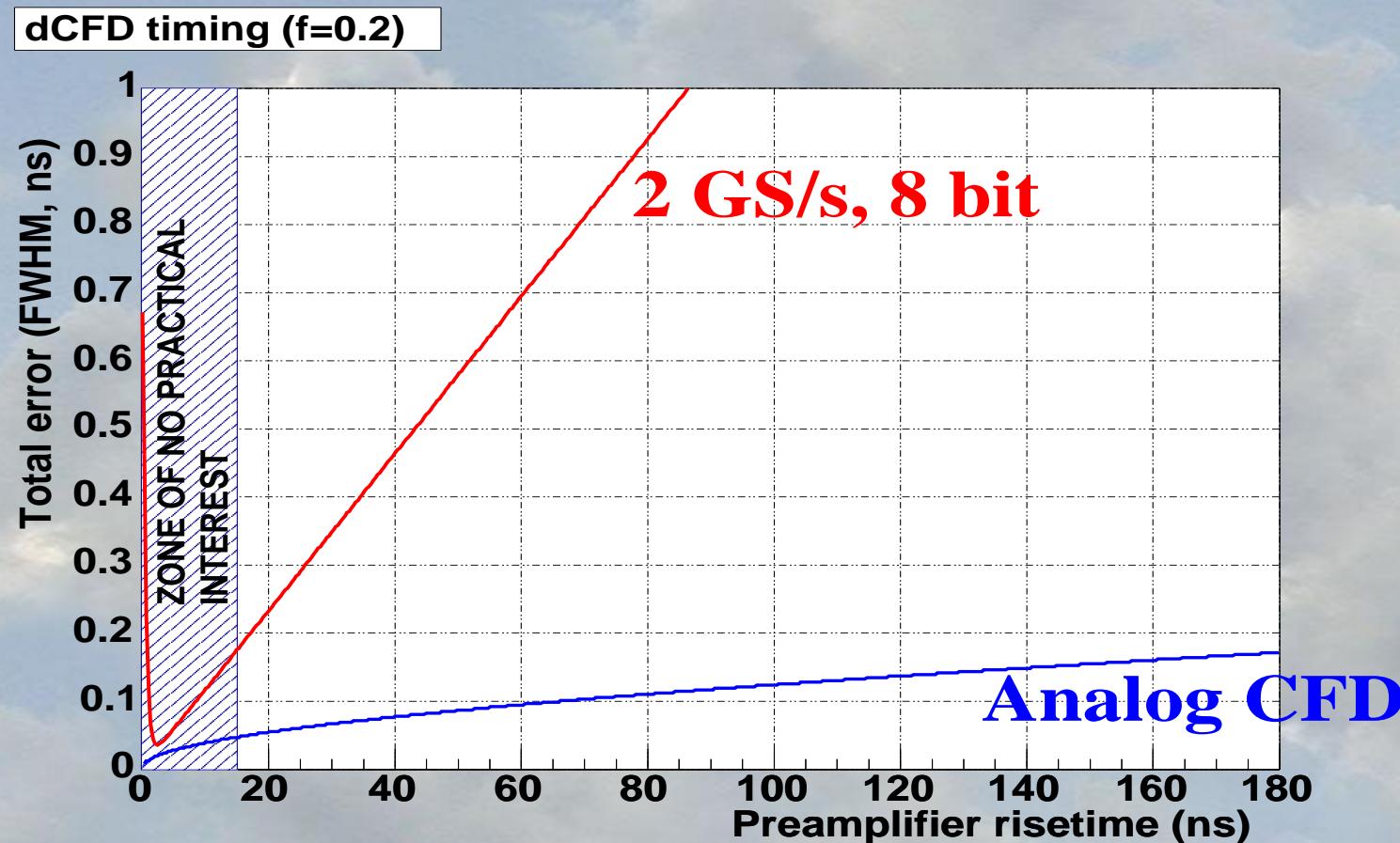
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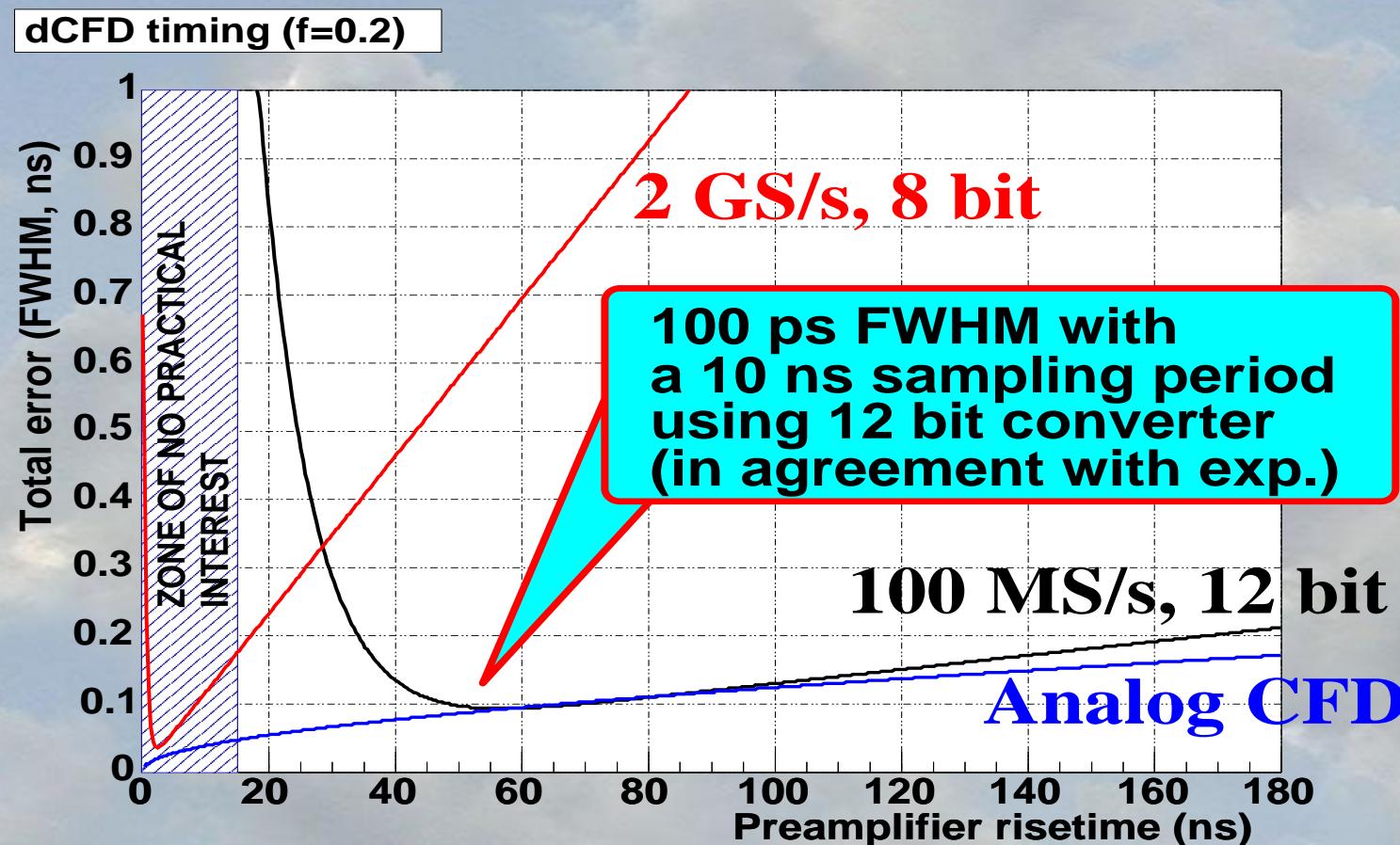
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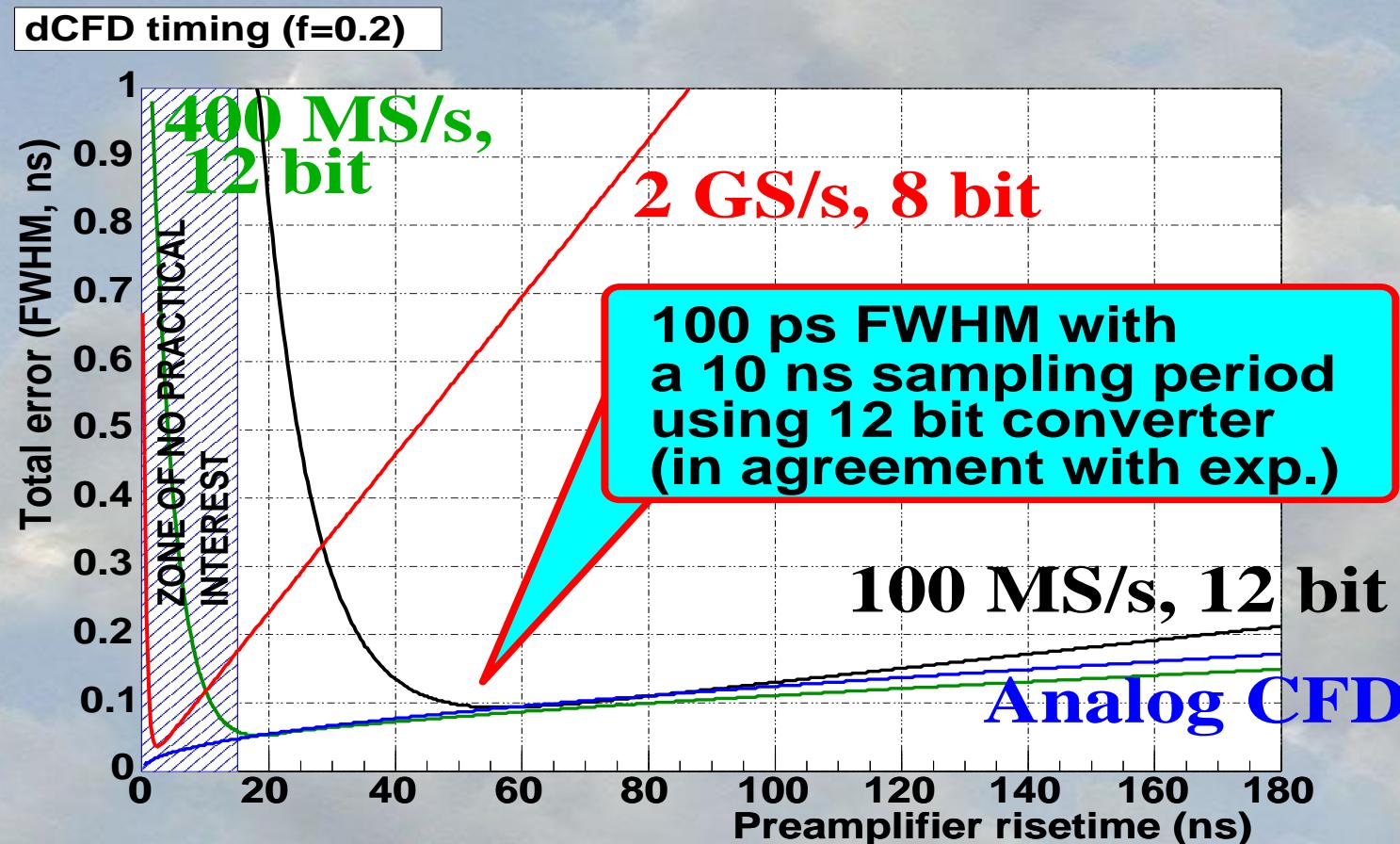
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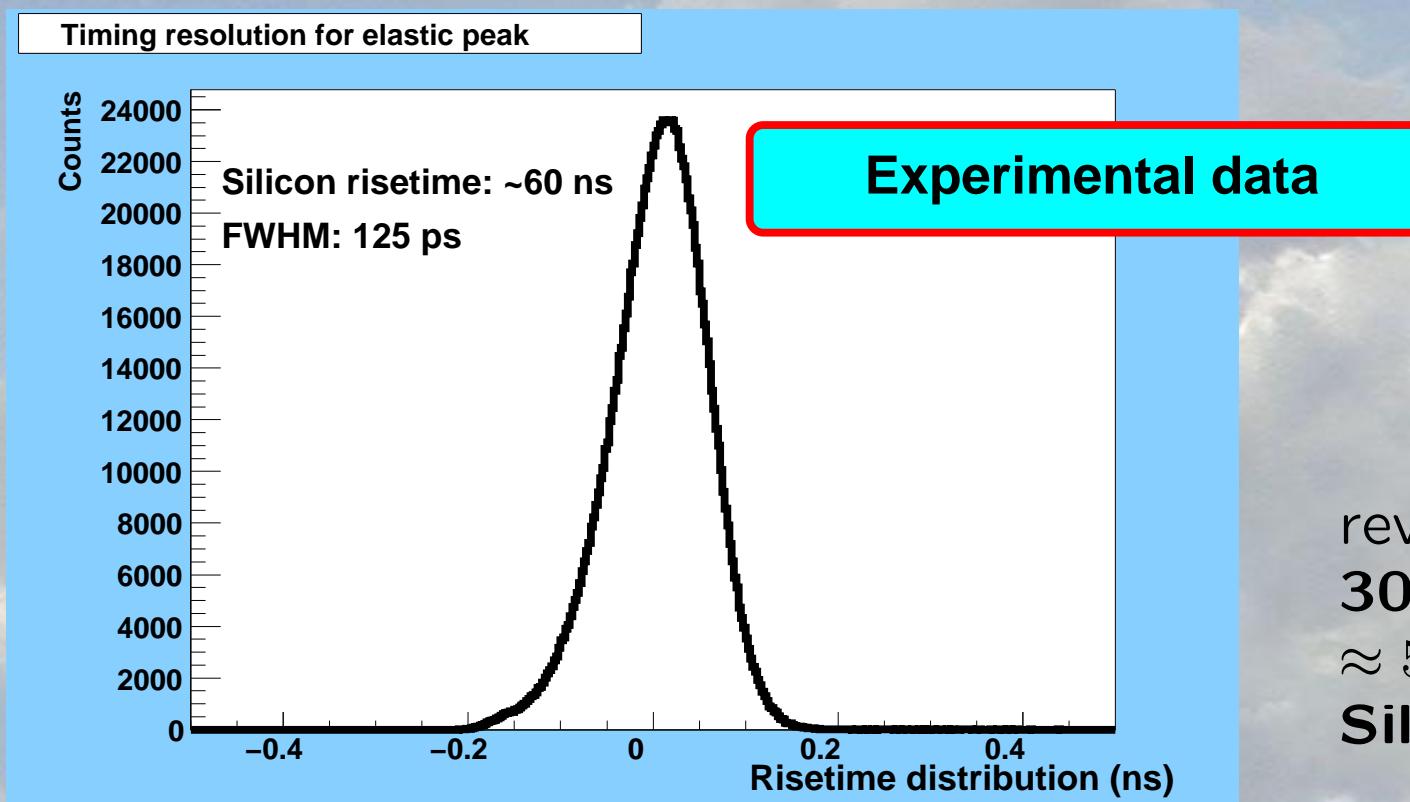


12 bit  $\Rightarrow$  Resolution 100 times smaller than sampling period



PSA analysis: differences between two **dCFDs**.

Timing of 250 MeV Oxygen elastic peak using a Si detector:



**Time difference between 90% and 10% dCFDs**  
**500 mm<sup>2</sup>** Si detector.

L.Bardelli *et al.*, submitted to NIM **A**

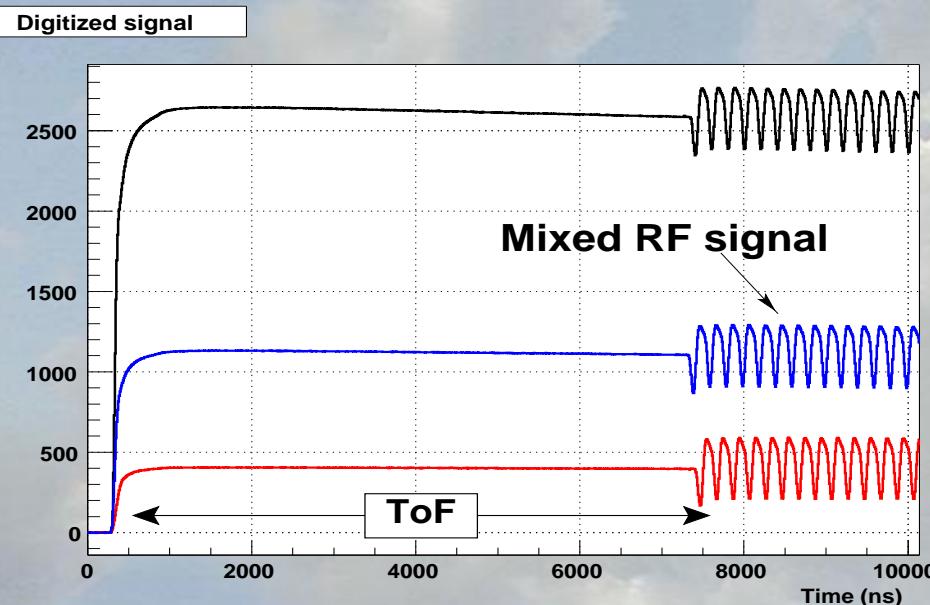
## Timing measurements 4

PSA analysis: differences between two **dCFDs**.  
**Time of Flight** or **coincidence** measurements?

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**Time of Flight** or **coincidence** measurements?

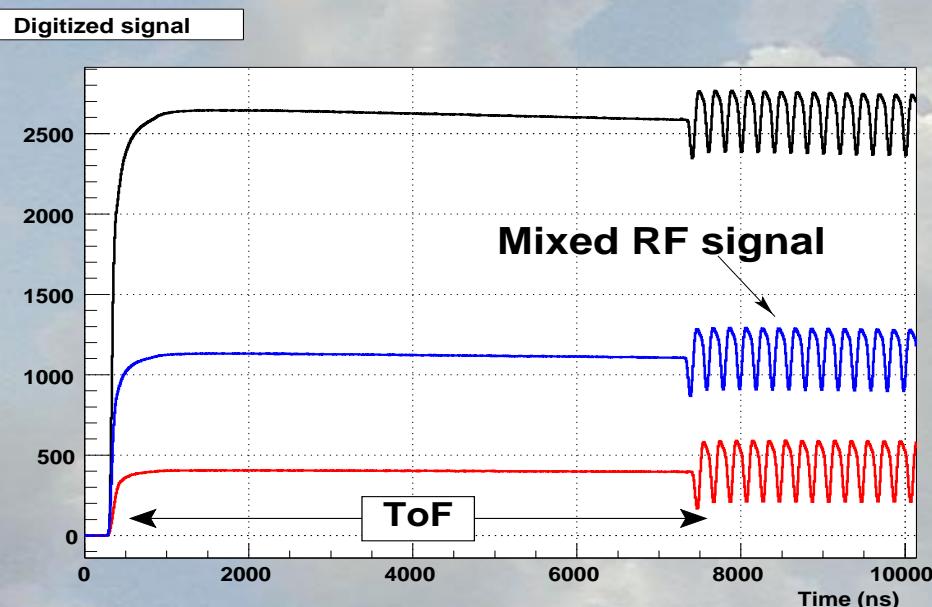
**Mix a common time reference signal with the preamplifier output:**



PSA analysis: differences between two **dCFDs**.

**Time of Flight** or **coincidence** measurements?

**Mix a common time reference signal with the preamplifier output:**



The DSP software can separate the “true” signal from the “reference” one and compute the time difference.

Using a train of pulses as reference the resolution can be significantly improved (i.e. 50 ps FWHM using 10 pulses)

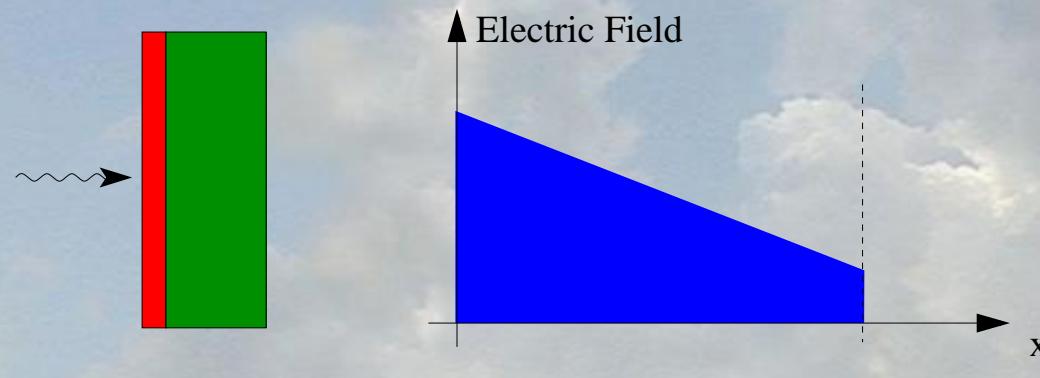
The same solution allows for **synchronization** between many channels: **coincidence** measurements possible.

L.Bardelli *et al.*, submitted to NIM A

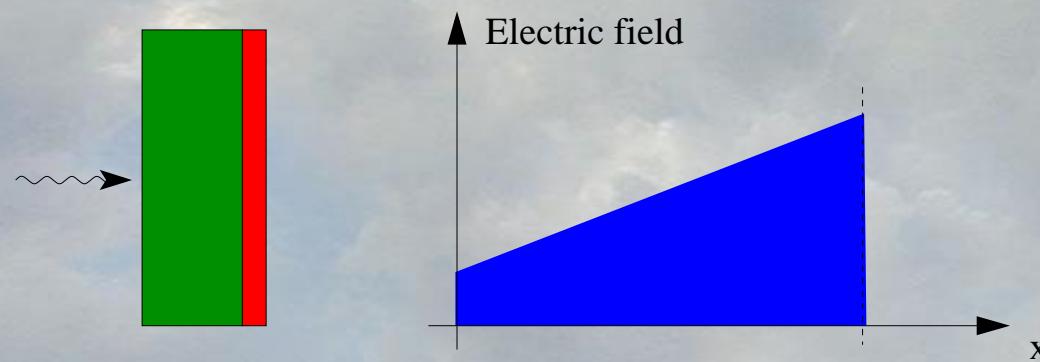
The standard  $\Delta E-E$  technique does not identify particles stopped in the Silicon detector.

One possible solution: **reverse mount Silicon detector**

**Standard configuration**



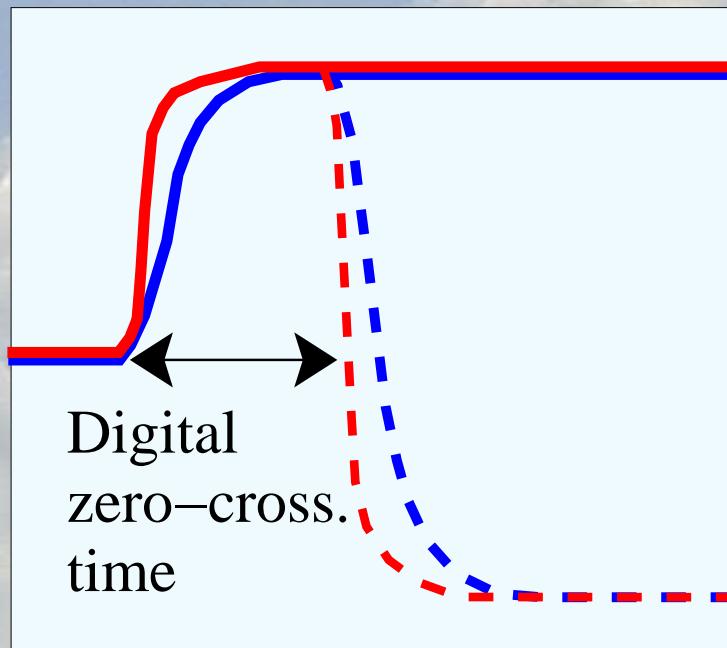
**Reverse configuration**



Increased  
**Pulse Shape**  
capabilities due to  
**charge collection**  
effects.

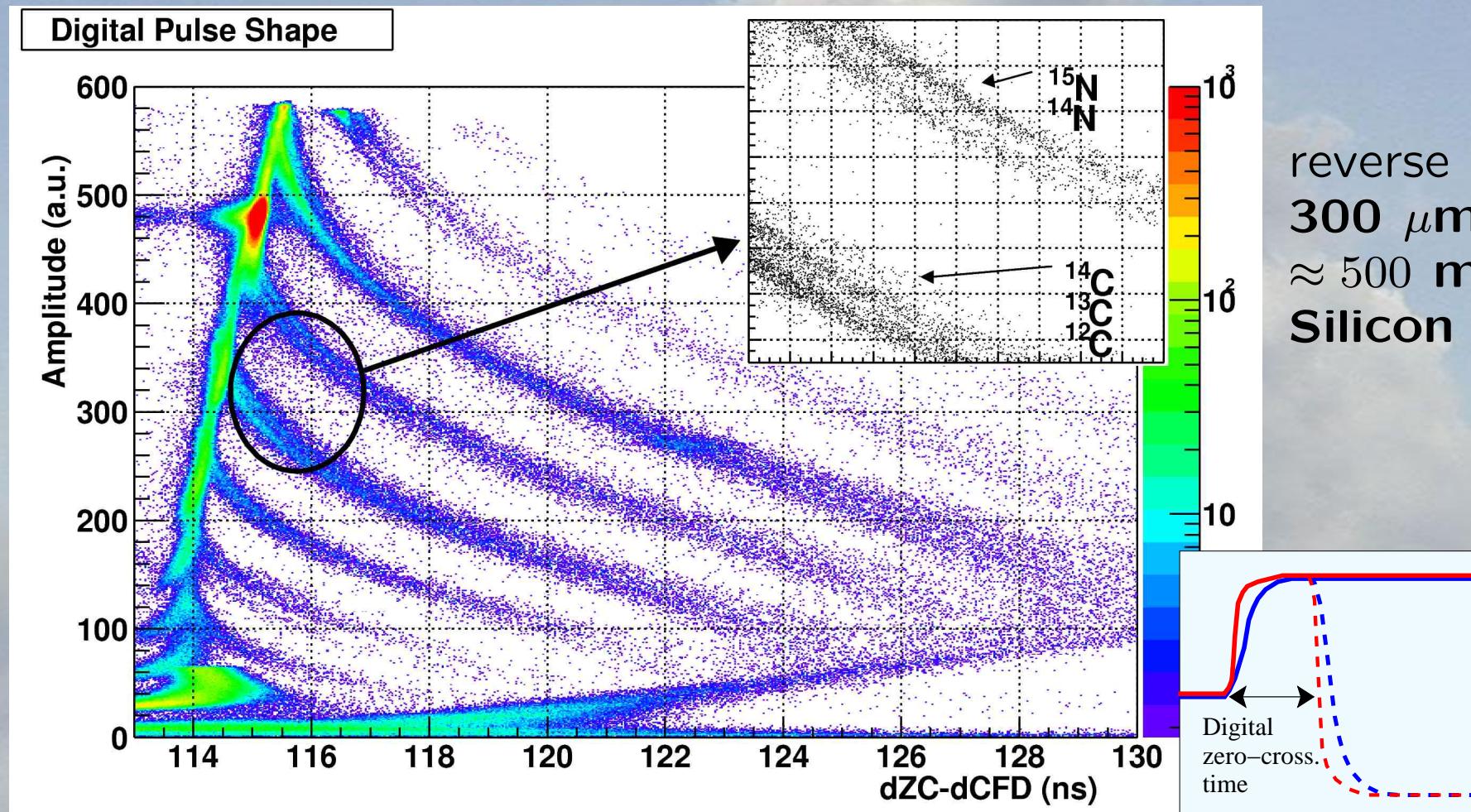


**Digital Amplitude** vs. **Digital Zero Crossing** time:





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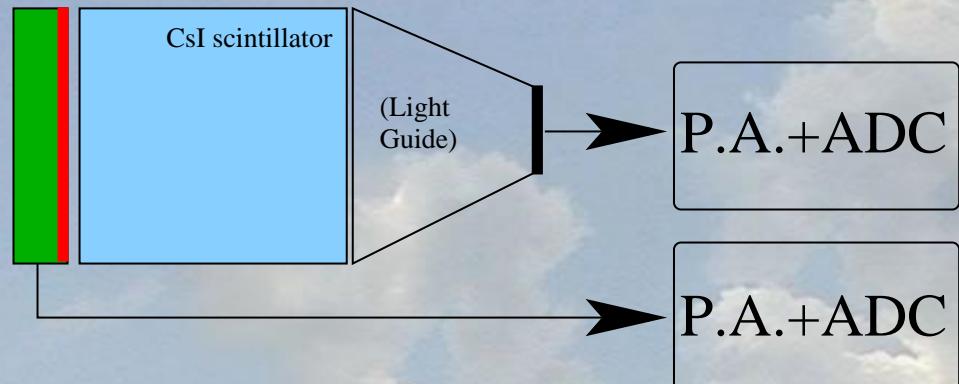


Evident **sub-nanosecond** resolution even with 10ns sampling



## Standard reverse mount Si-CsI:

Reverse mount Silicon Detector

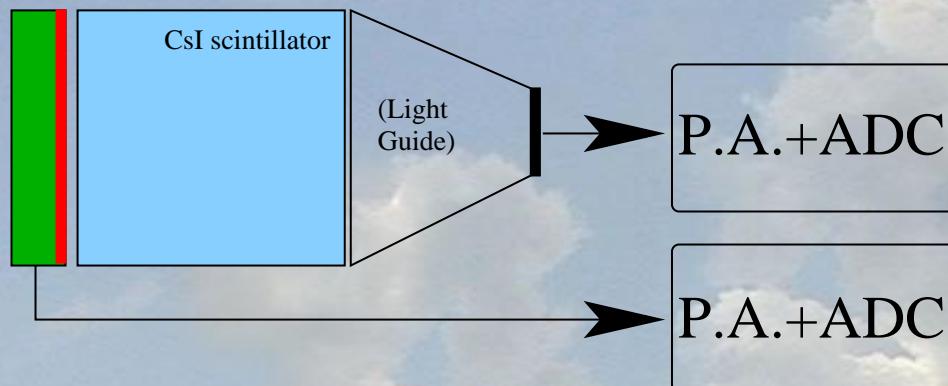


## Single Chip Telescope:



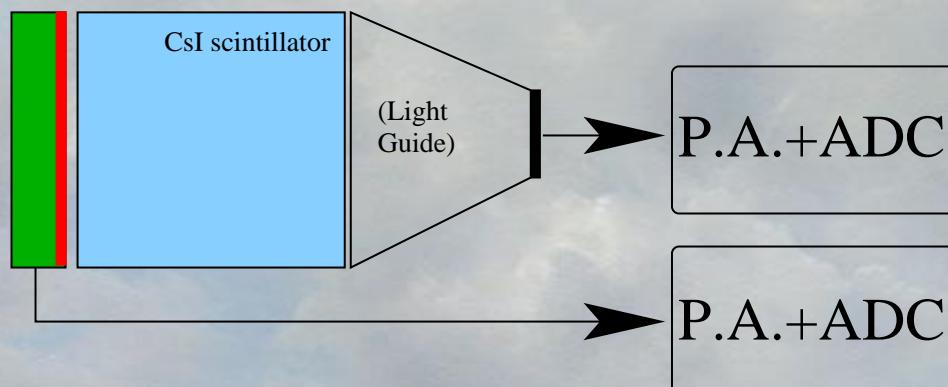
## Standard reverse mount Si-CsI:

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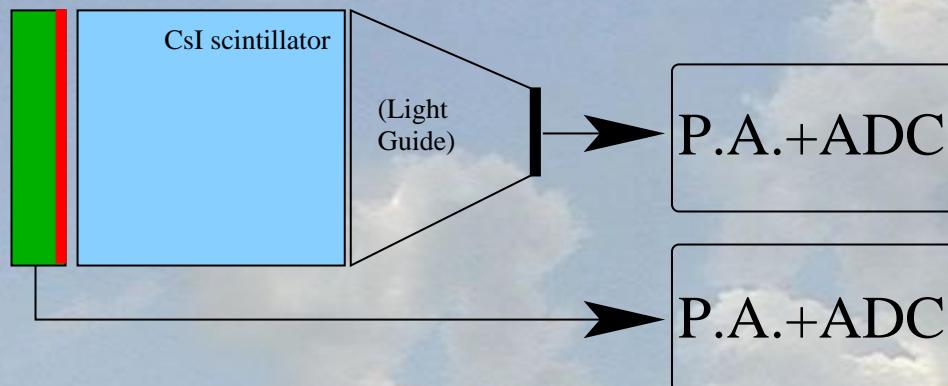
Reverse mount Silicon Detector





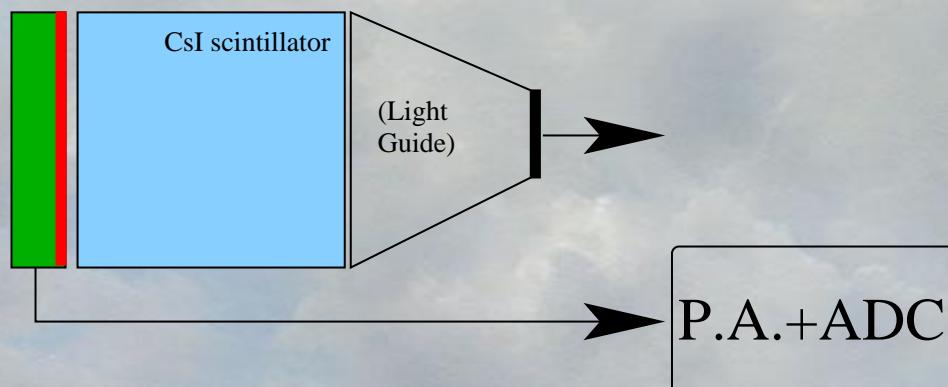
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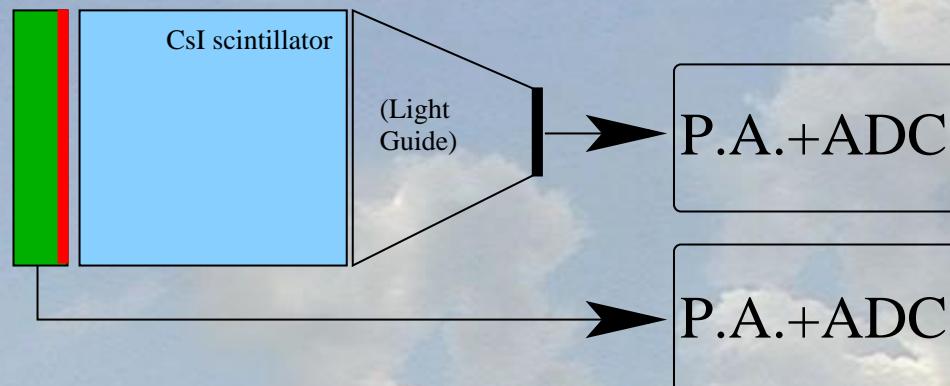
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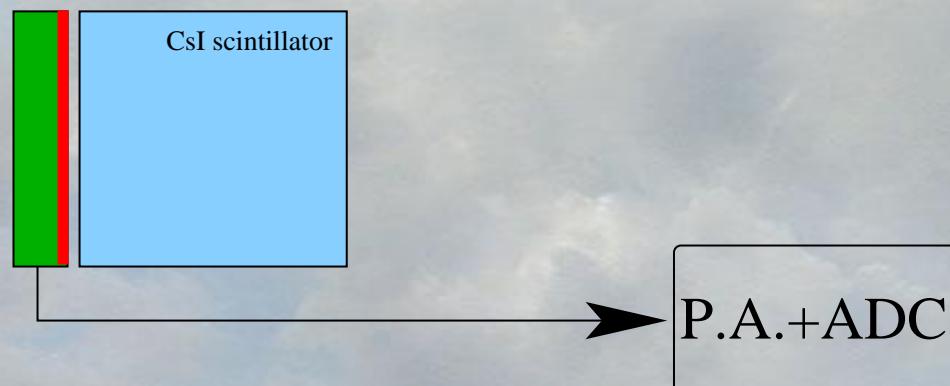
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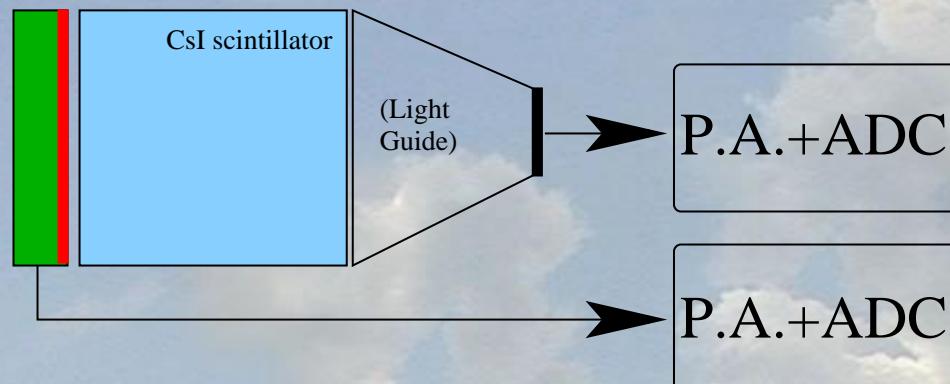
Reverse mount Silicon Detector





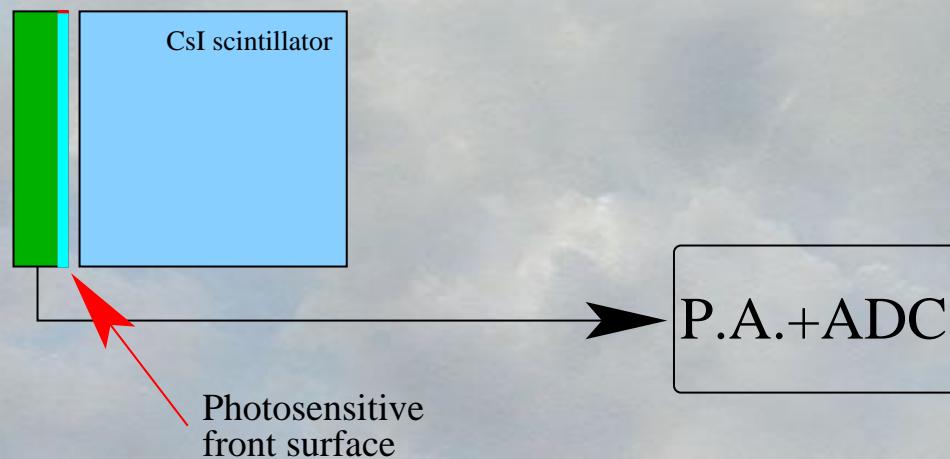
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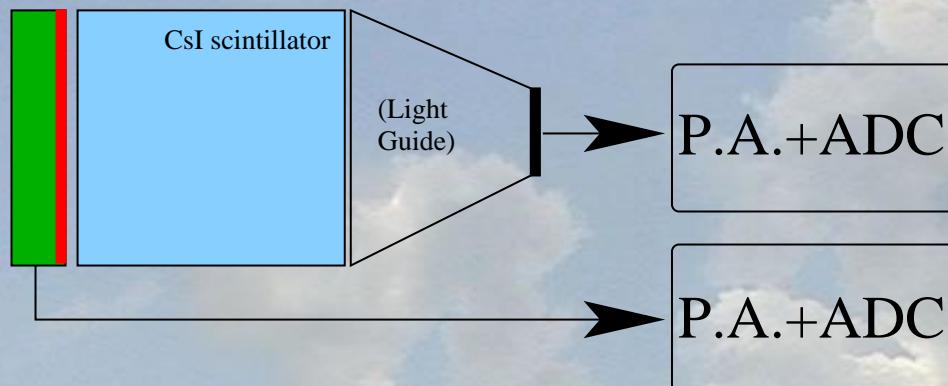
Reverse mount Silicon Detector





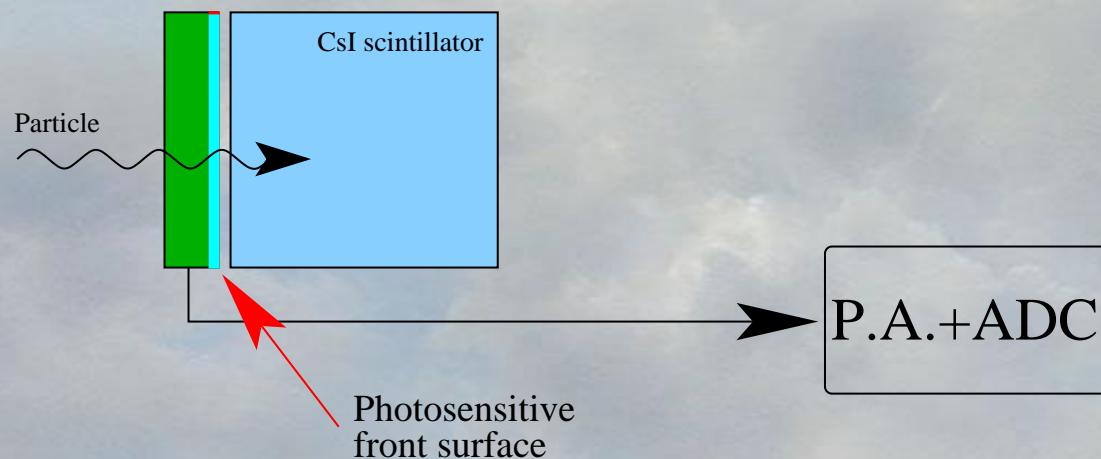
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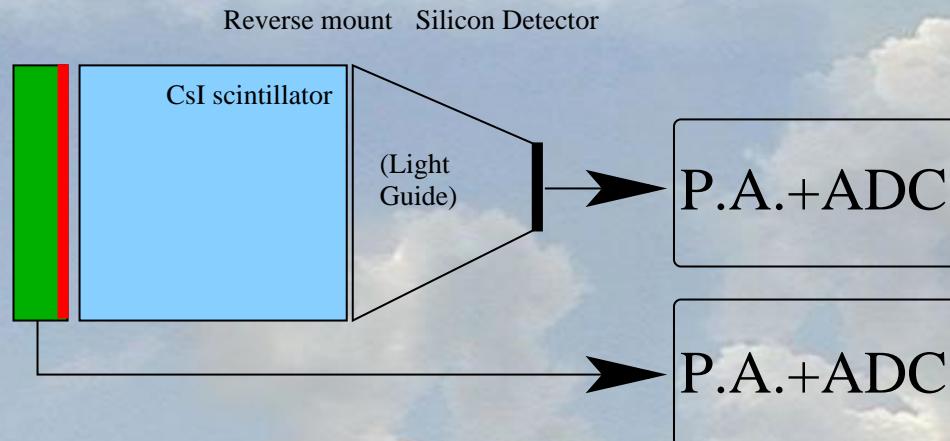
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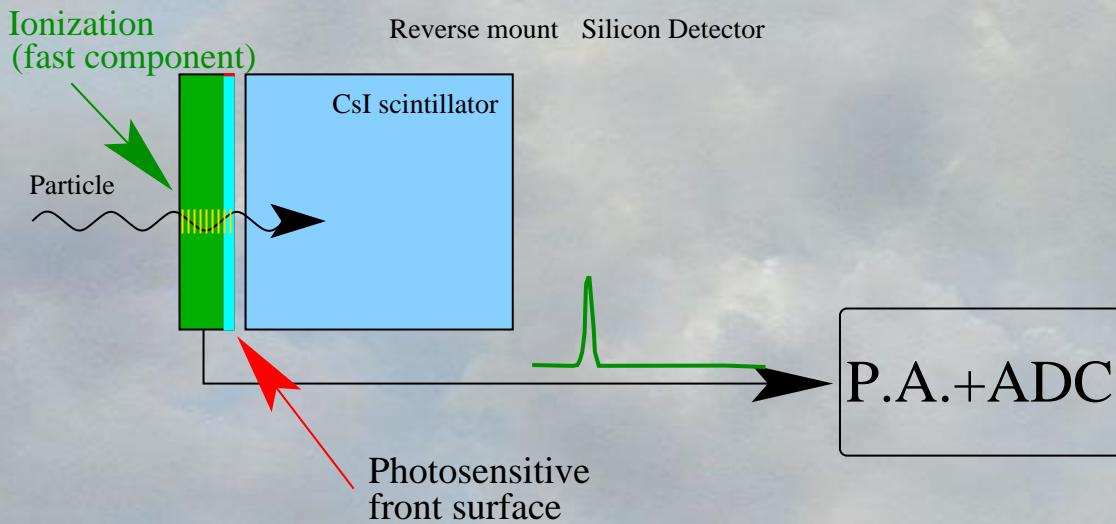




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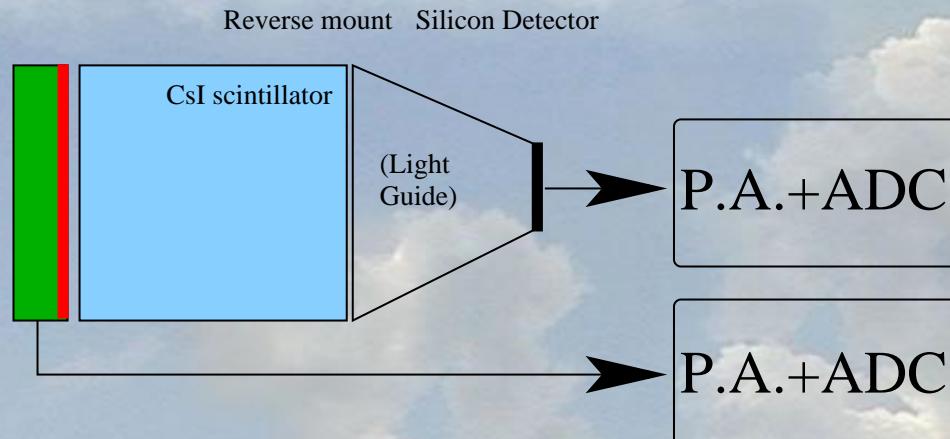


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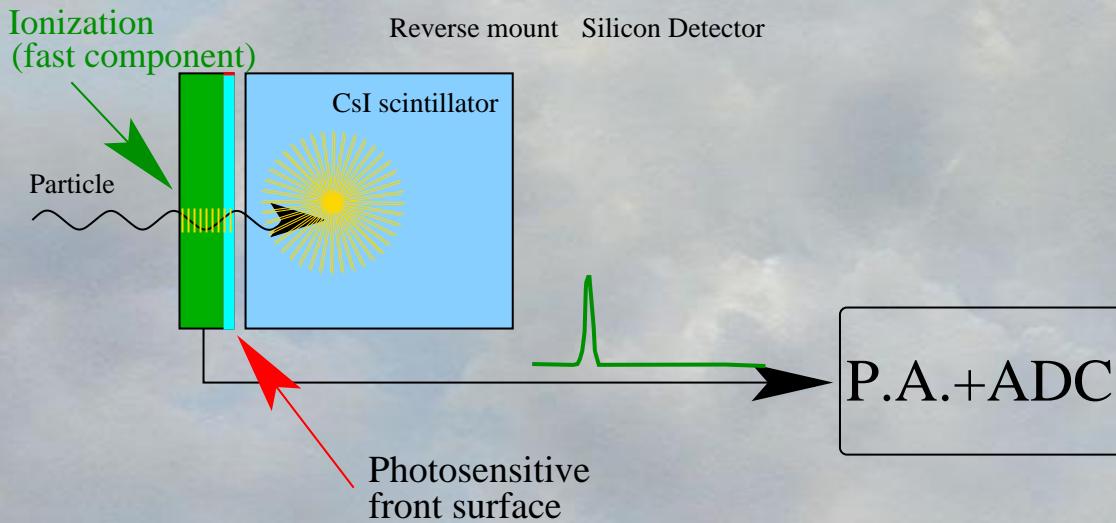




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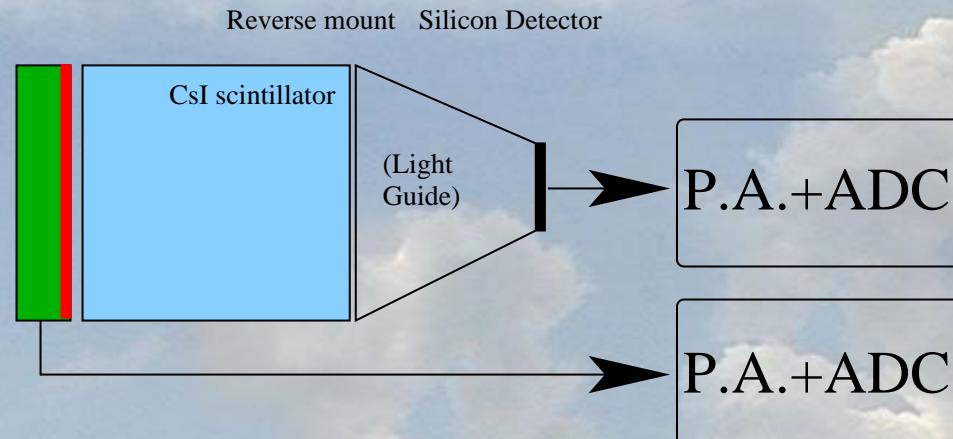


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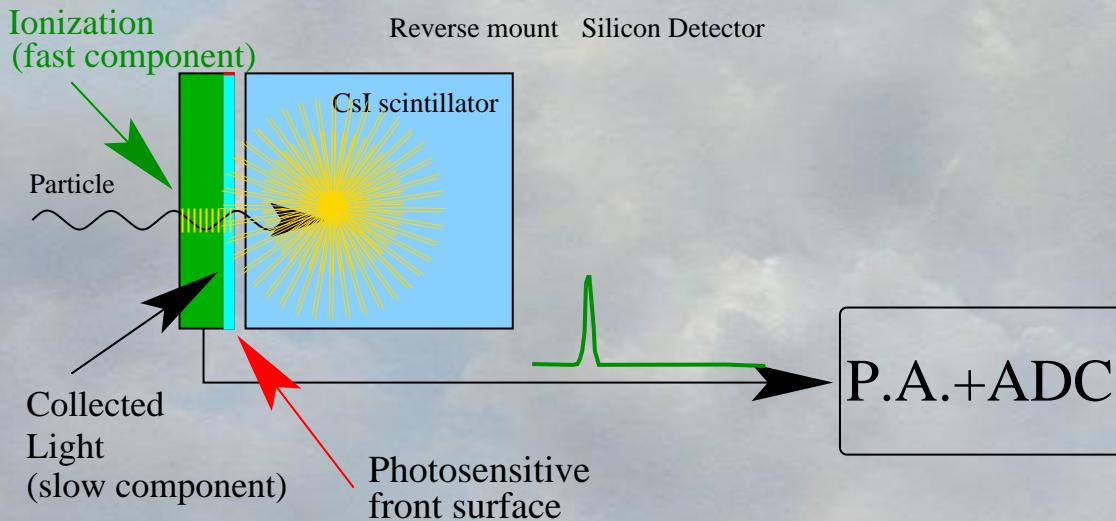




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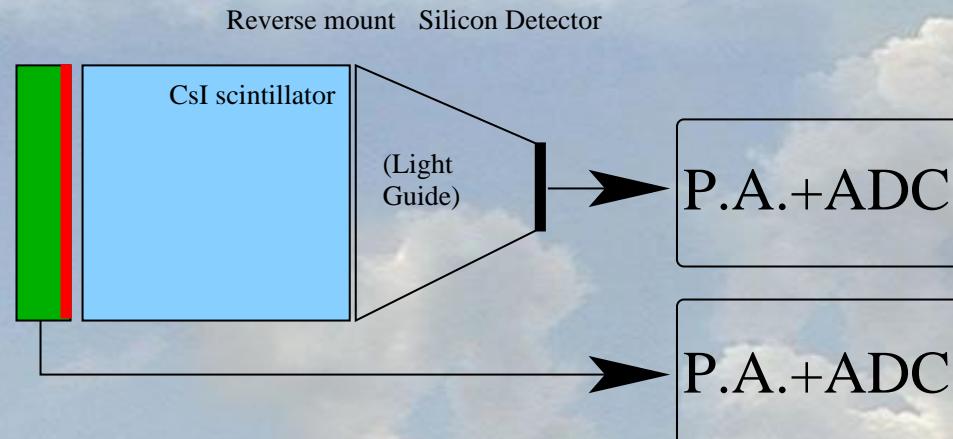


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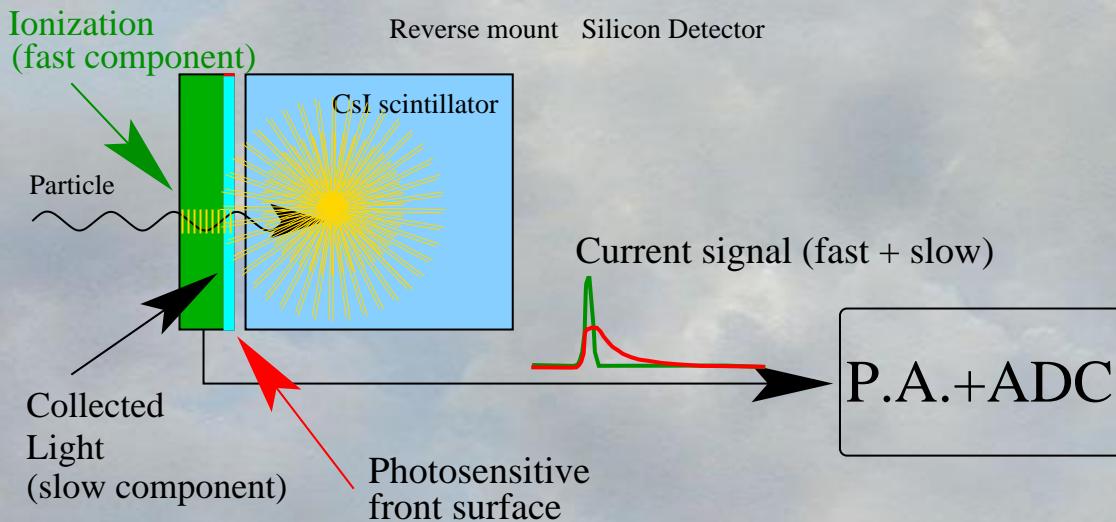




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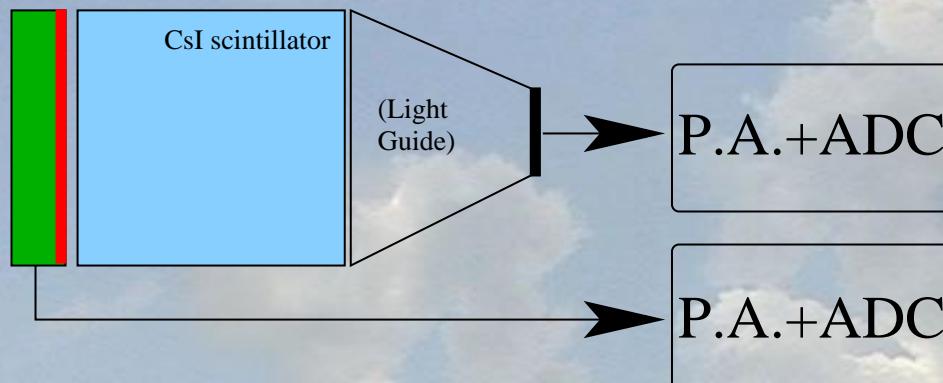
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## The Single Chip Telescope

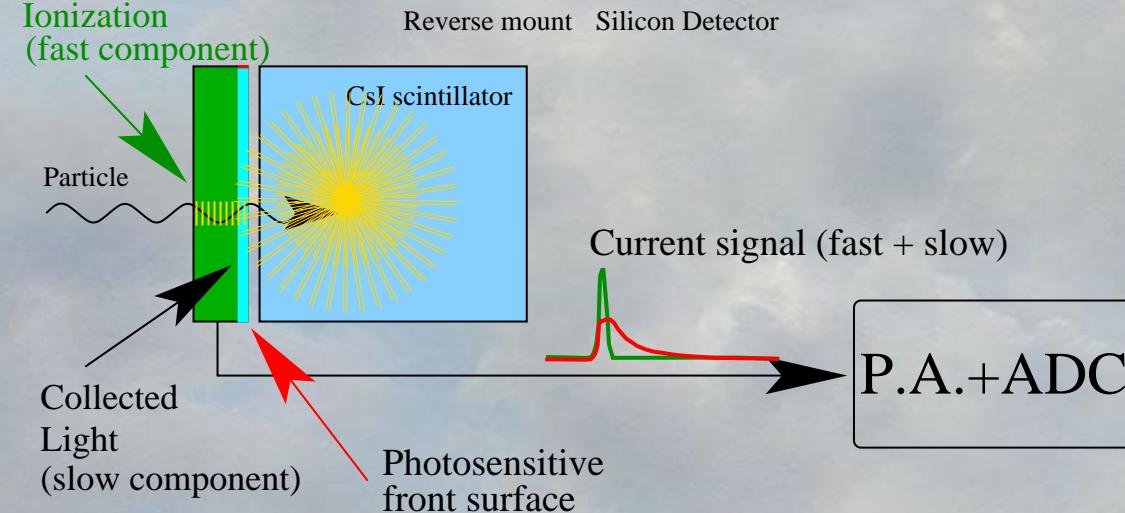
### Standard reverse mount Si-CsI:

Reverse mount Silicon Detector



### Single Chip Telescope:

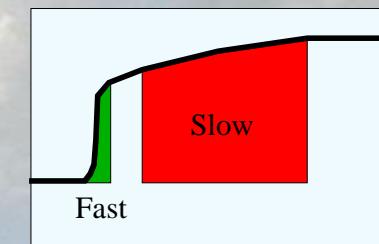
Ionization (fast component)  
Reverse mount Silicon Detector



This detector was first proposed in G.Pasquali *et al.*, Nucl. Instr. and Meth. **A301** (1991)

- **Fast** component from Ionization in Si, **Slow** from scintillation of CsI.
- **Stopped in Silicon:** **identical** to the previous case
- **Stopped in CsI:** **fast-slow discrimination.**

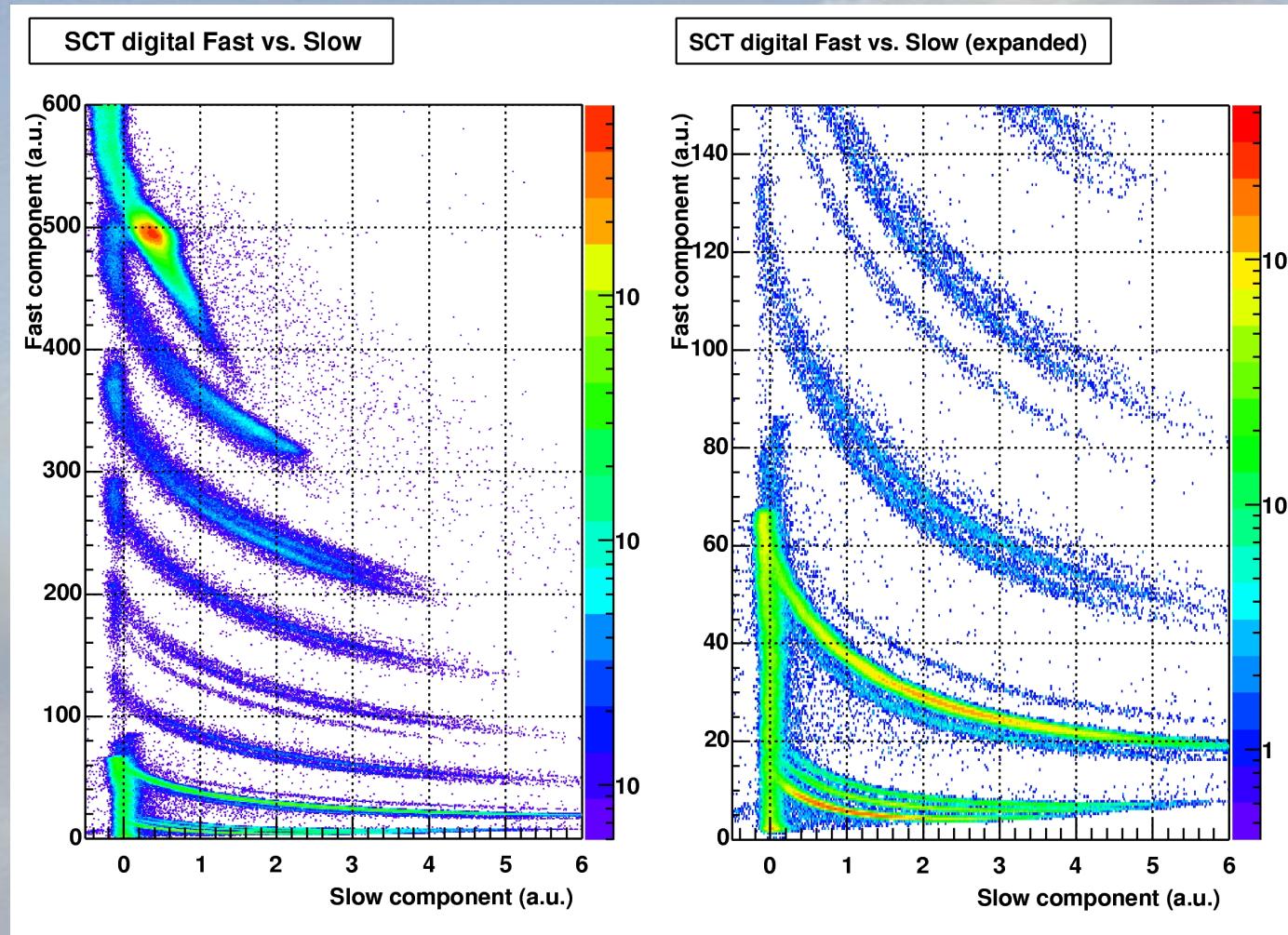
Example of preamplifier output:



**Only one digital acquisition channel**

## The Single Chip Telescope 2

Processing the signal coming from the preamplifier with two digital semigaussian filters ( $\tau_{fast} \simeq 200 \text{ ns}$ ,  $\tau_{slow} \simeq 1 \mu\text{s}$ ):



300  $\mu\text{m}$ ,  
 $\approx 500 \text{ mm}^2$   
 Silicon  
 $^{16}\text{O} + ^{116}\text{Sn}$  at  
 250 MeV

**Very first  
prototype**

## Time of Flight

In our experimental test we had a beam resolution of  $\sim 1.5\text{ns}$  (expected digital res. is  $\sim 100 \text{ ps}_{\text{FWHM}}$ )



→ No identification from Time of Flight (more tests needed).

## Time of Flight

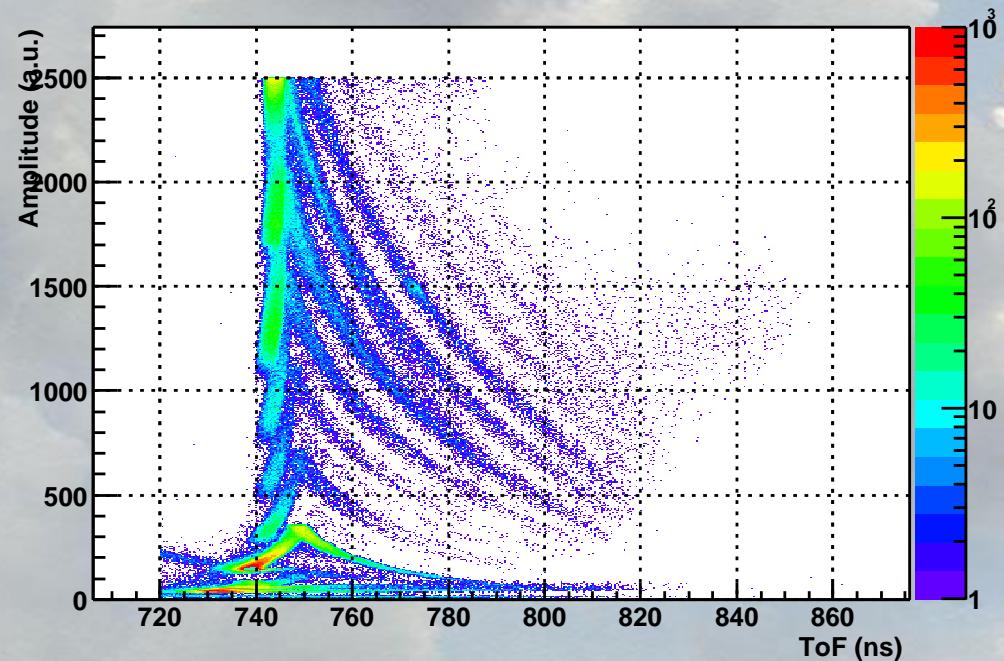
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**Distortion** of lines due to charge collection effects:  
**charge identification** dominant over **mass**!

*Same results using analog methods.*





- The main features of high resolution, fast sampling AD converters have been presented.
- Experimental examples of good resolution energy and timing measurements using digital sampling techniques have been discussed and applied to standard Si-CsI telescopes.
- A “new” detector has been proposed and the performances of the **very first prototype** discussed (experimental data collected with fast sampling ADC). More tests needed.



Effect of Silicon inhomogeneities on particle identification resolution

Some references:

- G.Pasquali *et al.*, Nucl. Instr. and Meth. **A301** (1991) 101.
- L.Bardelli *et al.*, Nucl. Instr. and Meth. **A491** (2002) 244.
- L.Bardelli *et al.*, Laboratori Nazionali di Legnaro Annual Report 2002.
- L.Bardelli *et al.*, submitted to NIM **A**.